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(71) Applicant (*for all designated States except US*): **INSTITUTET POLYMERUTVECKLING AB** [SE/SE]; Stenbocksvägen 21, S-182 62 Djursholm (SE).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): **JOHANSEN, Knut** [SE/SE]; Onkel Adamsgatan 9, S-582 35 Linköping (SE).

(74) Agents: **BRITA, Nilsson** et al.; Stockholms Patentbyrå Zacco AB, Box 23101, S-104 35 Stockholm (SE).

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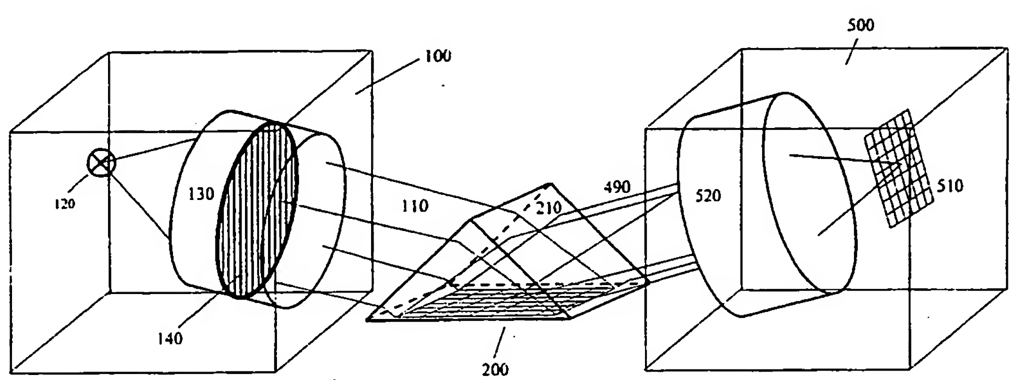

(57) **Abstract:** A two-dimensional imaging surface plasmon resonance (SPR) apparatus for optical surface analysis of a sample area on a sensor surface is disclosed. The apparatus comprises a sensor surface layer of a conductive material that can support a surface plasmon, such as a free electron metal, e.g. gold, silver or aluminum, a source of electromagnetic beams of two or more wavelengths that illuminate a two-dimensional surface area from either the front or the backside of the sensor surface layer, and a detector for simultaneous, or pseudo simultaneous, detection of two or more wavelengths of reflected intensities from the two-dimensional surface area, providing two or more two-dimensional images of the surface area, the two-dimensional images being a function of the effective refractive index at each point on the surface area. The two-dimensional images put together result in a color image. The apparatus is suitable for use in biological, biochemical, chemical and physical testing.

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IMPROVED IMAGING SPR APPARATUS

The present invention relates to an apparatus for optical surface analysis of a sample area on a sensor surface. The invention is particularly concerned with a two-dimensional imaging surface plasmon resonance (SPR) apparatus suitable for use in biological, biochemical, chemical and physical testing.

BACKGROUND OF THE INVENTION

There is an interest in surface sensitive techniques for quantifying molecular interactions. Properties that are of interest are e.g. concentration of free analyte in solution, surface concentration of molecules on sensor surface, reaction kinetics between interacting substances, affinity of said substances, allosteric effects or epitope mappings. Examples of interacting substances are antigen-antibody, protein-protein, receptor-ligand, DNA-DNA, DNA-RNA, peptides-proteins, carbohydrates-proteins, glycoproteins-proteins, etc.

There are many techniques that are suitable for this task, e.g. surface plasmon resonance (SPR), resonant mirror, grating couplers, interferometers, surface acoustic wave (SAW), Quartz Crystal Microbalance (QCM) etc. So far, SPR is the dominating technique.

Areas of application are e.g. measurement of concentration of substances in biological research, biochemistry research, chemical research, clinical diagnosis, food diagnostics, environmental measurements, etc. Kinetic measurements can be used to determine rate constants as k_{on} and k_{off}. Affinity measurements can be used to determine equilibrium association (K_A) or dissociation (K_D) constant as well as avidity.

SPR is a well-known phenomenon that consists of a bond electromagnetic wave, due to oscillations of electrons at the interface of a plasma. The surface plasmon can only exist at an interface between said plasma (e.g. a metal) and a dielectricum. A change in the optical constants of the dielectricum will change the propagation constant of the surface plasmon. The surface plasmon can be excited by light if the propagation constant of the light parallel to the interface is equal to, or close to, the propagation constant of the surface plasmon. Normally one uses the Kretschmann configuration [1] where a thin metallic film is applied on a prism, having a higher refractive index than the measured sample. The surface plasmon is then evanescently excited under total internal reflection, i.e. at an incident angle, normal to the surface, larger than the critical angle. At a certain incident angle, the component of the wave vector parallel to the surface meets the real part of the complex wave vector for a surface plasmon, and hence the light will couple into the surface plasmon and propagate at the interface between said plasma and said dielectricum. The surface plasmon will reradiate into

the prism, and for a certain thickness of said plasma a destructive interference occur, leading to zero or close to zero intensity of reflected light. For a smooth surface of said plasma, coupled light will be absorbed in said plasma and generate heat.

When molecules bind close to the interface (within the probe depth of the surface plasmon) the interaction can be detected by a shift in the resonance condition of the surface plasmon. This can be detected as a shift in a reflected light intensity.

The SPR sensor can be used in an imaging mode, also denoted microscopy. This was at first proposed by Yeatman in 1987 [2]. Other setups are proposed by Bengt Ivarsson EP958494A1: ANALYTICAL METHOD AND APPARATUS [3, 4], or GWC Instruments SPRimager [5]. The latter utilizes many wavelengths in a non-simultaneous manner.

The surface plasmon resonance (SPR) phenomenon was already described in 1959 [6] and SPR apparatuses for thin adlayer analysis have been thoroughly described since 1968 [1, 7]. SPR setups for biosensing were used for the first time in 1983 [8] and for imaging applications in 1987 [2, 9]. With imaging SPR, also denoted SPR microscopy, new applications arise, e.g., label free - real time - multi spot biochemical analyses [10, 11], which can increase the throughput tremendously. The pioneering work on imaging SPR was undertaken by Knoll *et al.*, who investigated surfaces patterned with Langmuir-Blodgett films [12, 13]. They also investigated the physical aspects of the technique, including lateral resolution [14], and proposed different setups, e.g. the rotating grating coupler [15].

There are in principal three different ways to measure changes in the SPR propagation constant. First, by measuring the reflected intensity (reflectance) at a flank of the SPR dip at a certain wavelength and incident angle. Second, by measuring the intensity of the reflected light versus the angle of incident light (angular interrogation). Third, by measuring the intensity of reflected light for different wavelengths at a certain incident angle (wavelength interrogation).

For zero-dimensional SPR (measurement of a single spot) said angular or wavelength interrogation requires at least a one-dimensional (linear) detector to make an instant measurement of the position of an SPR dip. For one-dimensional SPR (measurement of a single line) said angular or wavelength interrogation requires at least a two-dimensional (matrix) detector to make an instant measurement of the position of an SPR dip. In this case one dimension is used for the length scale (real image) and one dimension is used for the dip (either angle or wavelength). If two-dimensional SPR-measurement is performed, normally a dip cannot be resolved, i.e. one can normally only make an intensity measurement with a two-dimensional detector, i.e. for the two length scales. This means that only a limited portion of

the dynamic range (effective refractive index of the sample) can be measured, due to the limited extension of the SPR-dips (in either angel or wavelength). Only at a small range will the slope of the SPR-dip be high, which means that there will be a limited range of high sensitivity.

To overcome these drawbacks the present invention provides a two-dimensional imaging surface plasmon resonance apparatus wherein a set of wavelengths can simultaneously (or pseudo-simultaneously) be used, e.g. by using a multi-wavelength light source and a color camera.

SHORT DESCRIPTION OF THE INVENTION

A new multi-wavelength surface plasmon resonance (SPR) apparatus for imaging applications is presented. It can be used for biosensing, e.g., for monitoring of chemical and biological reactions in real time with label free molecules. A set-up with a fixed incident angle in the Kretschmann configuration with gold as the supporting metal is described, both theoretically and experimentally. Simulations of the sensor response based on independently recorded optical (ellipsometric) data of gold show that the sensitivity for 3-dimensional recognition layers (bulk) increases with increasing wavelength. For 2-dimensional recognition layers (adlayer) maximum sensitivity is obtained within a limited wavelength range. In this situation, the rejection of bulk disturbances, e.g. emanating from temperature variations, decreases with increasing wavelength. For SPR imaging, the spatial resolution decreases with increasing wavelength. Hence, there is always a compromise between spatial resolution, bulk disturbance rejection and sensitivity. Most importantly, by simultaneously using multiple wavelengths, it is possible to maintain a high sensitivity and accuracy over a large dynamic range. Furthermore, our simulations show that the sensitivity is independent of the refractive index of the prism.

The main advantages of the invention are:

Improvement of the performance of imaging surface plasmon resonance (SPR).

By simultaneously using two or more wavelengths, both sides of the SPR-dip can be tracked, and hence dip width and dip depth changes can be detected. This will enhance both the accuracy and precision of the measurement. Absorbing substances (e.g. colloid gold) will induce dip width and dip depth changes.

By simultaneously using two or more wavelengths the measuring range can be extended.

By simultaneously using two or more wavelengths a high sensitivity can be obtained for a larger measuring range.

By using two or more wavelengths, different points on the sensor surface with different effective refractive indices can be measured simultaneously with a high sensitivity, high accuracy, and a high precision.

The simultaneous use of two or more wavelengths will not only improve sensitivity, accuracy, and precision, but will also improve the speed of analysis, i.e. a higher throughput is obtainable.

SHORT DESCRIPTION OF THE DRAWINGS

Fig. 1a is a multi-wavelength imaging SPR setup. The parameters are explained in the text.

Fig. 1b shows schematically the apparatus with analog to digital converter and computer, and a flow cell with corresponding flow system (pump etc).

Fig. 2a shows the sensing unit in Kretschmann (back side illumination) configuration containing a prism, metal film and surface chemistry.

Fig. 2b shows a patterned sensor surface, with 6 x 7 = 42 measuring spots.

Fig. 2c shows a flow cell attached to the sensing unit.

Fig. 2d shows a version with exchangeable sensing chips.

Fig. 3 shows a sensing unit in the Otto configuration (front side illumination)

Fig. 4 shows an instrument with grating coupling

Fig. 5 shows a multi-detector arrangement.

Fig. 6 shows an imaging system.

Fig. 7 shows that it is possible to change incident angle.

Fig. 8a shows a setup with interchangeable filters (pseudo simultaneously)

Fig. 8b shows a rotating filter wheel.

Fig. 9 shows an experimental setup with a sophisticated imaging system.

Fig. 10 shows an experimental setup with a simple imaging system.

Fig . 11 shows an SPR-dip in angular interrogation.

Fig. 12 shows an SPR-dip in wavelength interrogation.

Fig. 13 shows the relationship between the incident angle for at the SPR condition and wavelength for gold (i.e. the dispersion relation). Two prism materials are shown, BK7 and SF11.

Fig. 14 shows the reflectance versus effective refractive index, at the sensor surface, for gold at three different wavelengths at an incident angle of 67 degrees.

Fig. 15 shows the sensitivity versus effective refractive index, at the sensor surface, for gold at three different wavelengths at an incident angle of 67 degrees. The curves in Fig. 15 are the derivatives of the curves in Fig. 14.

Fig. 16a-c shows reflectance images for an experimental setup at an incident angle of 68° and wavelengths 634, 692 and 751 nm, with gold as sensor metal layer and water as dielectricum.

The invention is now illustrated by description of embodiments with reference to the drawings and experiments, but it should be understood that the invention is not limited to the specifically disclosed embodiments.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides a two-dimensional imaging surface plasmon resonance apparatus which comprises a sensor surface layer of a conductive material that can support a surface plasmon, a source of electromagnetic beams of two or more wavelengths that illuminate a two-dimensional surface area from either the front or the backside of the sensor surface layer, and a detector for simultaneous, or pseudo simultaneous, detection of two or more wavelengths of reflected intensities from the two-dimensional surface area, providing two or more two-dimensional images of the surface area, the two-dimensional images being a function of the effective refractive index at each point on the surface area.

In an embodiment of the apparatus of the invention the conductive material is a free electron metal, such as gold, silver or aluminum. The sensor surface layer may be a grating.

In a preferred embodiment of the invention a prism is provided as a support for the sensor surface layer. The sensor surface layer may be supported on a planar transparent substrate plate, such as glass and plastics, optically attached to the prism, preferably by an index matching fluid, gel or glue.

The light source used in the apparatus of the invention may be selected from the group consisting of a) one or more monochromatic light sources, such as light emitting diodes or lasers, b) a glowing filament lamp, such as a Tungsten lamp, and c) a charge discharge lamp, such as a Xenon or Mercury lamp.

In an embodiment of the invention, the light from the light source is coupled into the sensor surface layer by a lens, fiber optics, or a mirror.

In another embodiment the light source provides a variable incident angle.

In yet another embodiment the light from the light source is collimated.

In still another embodiment the light of different wavelengths from the light source are impinging on the sensor layer, and by a rotating filter, pseudo-simultaneous impinging on the detector, which is synchronized to said rotating filter. The rotating filter can be placed anywhere in the optical path between the light source and the photo detector, i.e. before and after the sensor surface.

The detector used in the apparatus of the invention may be selected from the group consisting of a two dimensional array camera, charge coupled device (CCD), charge injection device (CID), photo diode array detector (PDA), photomultiplier and a CMOS sensor.

In an embodiment of the invention the detector has a mosaic filter.

In another embodiment two or more detectors are provided, and these are fitted with beam splitters and filters, such as interference filters, to enable measurement of different spectral properties.

In yet another embodiment the filter(s) is(are) adjustable.

In still another embodiment the detector(s) is(are) connected via an optical fiber bundle.

In a preferred embodiment the detector is a photographic film.

The apparatus of the invention may have a lens system, such as fixed focal length or a zoom, to magnify or reduce the image.

In a most preferred embodiment the apparatus operates with wavelengths at or close to the highest slope of the dip, either reflectance versus wavelength or reflectance versus the effective refractive index seen by the surface plasmon.

In a further embodiment of the invention, the light that hits the detector is p-polarized by a polarizer.

In another preferred embodiment the two-dimensional images put together result in a color image.

The invention will now be described with reference to the drawings.

Fig. 1a illustrates one embodiment of the apparatus of the invention wherein a collimated input beam **110** emanates from an illumination system **100** onto a sensor unit **200**, preferably a prism (equilateral, right angle, hemispherical or aspherical) **210**. The reflected light from said sensor unit is projected on an imaging system **500**.

Fig. 1b illustrates schematically an apparatus of the invention with a computer **900** and an analog to digital converter **800** connected to the imaging system **500**.

Fig 2a shows the prism **210** of **Fig.1a** onto which a metal film **220** has been evaporated (thermally or by sputtering). The prism **210** is transparent (glass or a polymer). A glass prism can be made of high refractive index e.g. flint glass or standard glass e.g. crown glass. A polymer prism can be made of non-crystalline plastics like polymethylmethacrylate, polycarbonate, styrene, SAN, glycol modified PET, etc. The metal film sensor is preferable gold if high chemical resistance is wanted. The metal film sensor can be silver if high sensitivity is preferred, but chemical resistance is not critical. The metal film is preferably evaporated on an evaporated (thermally or sputtered) adhesion layer **230**. The adhesion layer **230** is preferably chromium or titanium. The adhesion layer is typically 0.5 nm thick. The adhesion layer is normally not a totally covering film due to the limited thickness. A too thick adhesion layer will lower the sensitivity of the apparatus. The thickness of said gold film is typically 45 to 50 nm. The thickness of said silver film is typically 56 nm. The metal layer **220** may have the form of a pattern. The pattern can be made by reactive etching using a photo lithography process. The metal layer may be covered by a linker layer **240**. The linker layer can be an alkane thiol. The alkane thiol may function as a handle to specific molecules **250a**, **250b**, etc. The attached specific molecules can have an affinity to other species **260a**, **260b**, etc. The linker layer **240** can be in the form of a pattern. The metal film can be provided with a pattern by use of an inert film **270**. The inert film can be photosensitive benzocyclobutenes (photo-BCB).

Fig 2b shows the base of the prism **210**, or transparent substrate 300 (**Fig. 2d**).

Fig 2c shows the prism **210** onto which a flow cell **280** has be attached. To avoid leakage, a seal **290** can be inserted between the prism **210** and the flow cell **280**. The flow cell can be made of a plastic material (polymethylmethacrylate, polycarbonate, styrene, polyvinylchloride, polyetheretherketone, polyamide etc.). The flow cell can be fitted to a flow system **295**. The flow system may comprise a pump **297** (e.g. syringe pump or peristaltic pump), valves and tubing, as illustrated in **Fig 1b**.

Fig 2d shows the prism 210 with a metal film **220** evaporated on a transparent substrate **300**. The substrate may be a plastic material, glass or semiconductor. The substrate **300** has preferably the same or similar optical constants as the prism **210**. To obtain good optical contact between said prism and said transparent substrate, an optical interface **310** is used. The optical interface **310** should have optical constants equal to or close to those of said prism and said transparent substrate. The optical interface may be an index matching fluid, a gel, or a glue.

Fig 3 shows an optical system denoted Otto configuration **320**. Said Otto configuration utilizes an air or liquid gap **330** to evanescently excite the surface plasmon.

Fig 4 illustrates a setup wherein the multi wavelength SPR can be excited by a corrugated metal film (grating) **340**. In this case the metal film sensor does not need to be thin.

Referring to **Fig. 1a**, the illumination system **100** comprises a light source **120**. Said light source can be a glowing filament, e.g. a tungsten-halogen lamp, or an arc discharge lamp, e.g. Xenon lamp, or lasers, e.g. diode lasers, dye lasers etc, or light emitting diodes (LEDs). Radiation from said light source is collected by a lens system **130,** which creates a collimated (parallel) light beam **110**. The lens system **130** can be a positive lens, e.g. f=150mm, or a condenser system, or a more sophisticated lens system. At some point in the beam of said illumination system a polarizer can be inserted **140**. Said polarizer can be a dichroic sheet, Glan-Thompson polarizing prisms, Glan-Taylor polarizing prism or Wollaston prisms. The polarizer or polarizing equipment shall transmit light parallel to the plane of incidence (p-polarized or transverse magnetic, TM). The use of a polarizer will improve performance, but is not necessary. A surface plasmon can only be excited by p-polarized light, hence light polarized transverse the plane of incidence (s-polarized or transverse electric, TE) will be reflected at the sensor surface. Absence of a polarizer will hence decrease the depth of the SPR dip, which may be a disadvantage, due to non-informative signal added to the informative SPR signal at the imaging system **500**.

The imaging system **500** utilizes at least one area detector **510,** which can be a photographic film, e.g. a color film (negative or dia positive), an electronic photo device, e.g. photo diode array, charge coupled device (CCD), charge injection device (CID), CMOS array etc. The area detector **510** may be a color device. The color device may include a mosaic color filter.

Fig. 5 illustrates an imaging system **500** that consists of more than one area detector **510a**, **510b**, **510c**, one for each wavelength. In this case, a reflected light beam **490** is divided by beam splitters **550** and color filters **560a, 560b, 560c**, in the same way as used in commercial 3 CCD video cameras. The color filters can either be narrow and non-overlapping in wavelength, or be broad with overlapping wavelengths.

Fig. 6 illustrates a setup for improving image quality by use of an imaging lens **520**. The imaging lens **520** can be an ordinary focusing camera lens, and it can be further improved by adding a cylindrical lens **530**. Image restitution is possible by adding a secondary prism **540**, cylinder lens or by tilting the area detector.

Fig 7 shows an embodiment wherein the incident angle of the light beam 110 can be altered by rotating the illumination system **100** with respect to the prism **210**. The imaging system **500** is rotated by the same amount as the prism **210**, but in the other direction. The rotation can be performed by a goniometer, i.e. a θ, 2θ system, where the illuminating system is fixed and the prism is rotated θ and the imaging system is rotated 2θ.

Fig 8a shows an embodiment wherein the multi-wavelength feature described in relation to **Fig 7** can be fulfilled in a pseudo simultaneously manner with a filter device **600**. The filter device **600** can be a rotating filter wheel as illustrated in **Fig 8b**. The rotating filter **600** can be a band pass filter **610a, 610b, 610c, etc.** Said band pass filter can be an interference filter. Another method to change wavelength is to use an electro-optical device, e.g. a Fabry-Perot cell. Change of filter is synchronized with the detector.

The two-dimensional imaging surface plasmon resonance apparatus of the invention can be oriented in any direction (vertical, horizontal or any angle between). The sensor surface can be faced upwards, downwards or any arbitrary direction in space.

DESCRIPTION OF EXPERIMENTS

It is shown how SPR imaging can be performed with a color camera. The camera allows simultaneous intensity measurements at different wavelengths, which will increase the dynamic range and increase the sensitivity and accuracy over a larger range of the refractive index of the sensing medium. The sensing medium can be a 3-dimensional bulk material or a 2-dimensional adlayer. For the latter, the thickness change can be monitored if the refractive indices of both the adlayer and the surrounding medium are known.

For an SPR apparatus working in angular interrogation (**Fig. 11**, reflectance versus incident angle) simulations (with Fresnel equations) and measurements show that the resonance angle θ_{sp} increases $\Delta\theta_{sp}$ for increasing effective refractive index, e.g. by an adlayer formation (case 2 in Fig. 11). Case 1 in Fig 11 is without an adlayer, i.e. a lower effective refractive index is seen by the sensor. Simulations (Fresnel equations) and measurements show that the resonance wavelength increases with increasing effective refractive index (e.g. adlayer formation) for an apparatus working in the wavelength interrogation **(Fig. 12).** The conditions used in the example is a gold film of thickness, d_m, equal to 50 nm, an incident angle, θ, equal to 67°, and a prism **210** made of BK7 glass. The curves in Fig. 12 illustrate the reflectance versus wavelength for effective refractive indices, n_a, from 1.33 to 1.37.

Referring to **Fig. 13** and Fresnel calculations, the SPR dip-valley (minimum reflection) will move in a right upward direction upon increasing effective refractive index,

n_a, of the dielectricum, e.g. an adlayer formation. The curvature of the dip-valley is an effect of the SPR-dispersion relation emanating from the dispersion of the metal (i.e. change of dielectric constant as a function of wavelength). The incident angle, wavelength, refractive index of the prism **210** and effective refractive index of the sample for the SPR imaging equipment are coupled (due to the dispersion relation of the surface plasmon). Curves from two different setups are shown in **Fig. 13**, one corresponds to a prism **210** made of BK7 glass (refractive index approximately equal to 1.5), and the other corresponds to a prism **210** made of SF11 glass (refractive index approximately equal to 1.5). The incident angle is be plotted versus the refractive index of the sample (**Fig. 14**) for the same conditions as in **Fig. 12**, using three wavelengths (700, 800, and 900nm). The incident angle and wavelength is preferably chosen so that the derivative (**Fig. 15**) of the reflectance versus effective refractive index (**Fig. 14**) is maximized. The derivatives of the reflectance versus effective refractive index for an example with a 50 nm gold film, at an incident angle of 67°, for three different wavelengths (700, 800, and 900nm), and different effective refractive indices are shown in **Fig. 15**.

An example of a sensor surface that has individual sensor spots on a gold film **220** is shown in **Fig. 16** for wavelengths 634, 692 and 751 nm, at an incident angle of 68° and a prism made of BK7 glass. The effective refractive index of the sample is approximately 1.33.

EXAMPLE 1

Fig. 9, which illustrates one embodiment of the two-dimensional imaging surface plasmon resonance apparatus of the invention, utilizes a white light source comprising a 300 W Xenon Arc lamp **800** (Oriel Inc., Stratford, CT, USA), in a housing **810** (Oriel) containing a F/1 condensing lens assembly **820** (Oriel). Collimated light is focused by a positive lens, f=150 mm **830** (Oriel), onto a 400 m pinhole **840** (Melles Griot Inc.). A second lens, f=150mm **850** (Melles Griot), creates a collimated light beam **875**, which is filtered by a filter wheel **860** consisting of three interference filters of center wavelength 634, 692 and 751 nm respectively. All filters have a bandwidth of 10 nm. Said collimated beam is plane polarized by a dichroic sheet polarizer **870** (Melles Griot). The collimated light **875** impinges on an equilateral prism **880** made of BK7 glass (Melles Griot). Onto said prism is a glass substrate **883** attached by an index matching fluid (Cargille Inc.). The glass substrate contains the metal film supporting the surface plasmon resonance. The reflected light **877** from said prism **880** is directed to a right angle prism **890** made of BK7 glass (Melles Griot). Said prism **890** restitutes the image. A cylinder lens, f=100 mm, **900** is put between the said

right angle prism **890** and a camera lens, Nikon micro f=60mm, f/2.8, **910**. The image from the sensor surface is projected on a CCD camera **920** (Orbis 2, Spectra Source Inc.)

<u>EXAMPLE 2</u>

Fig. 10, which illustrates another embodiment of the two-dimensional imaging surface plasmon resonance apparatus of the invention, utilizes a white light source comprising a 300 W Xenon Arc lamp **800** (Oriel Inc., Stratford, CT, USA), in a housing **810** (Oriel) containing a F/1 condensing lens assembly **820** (Oriel). Collimated light is focused by a positive lens, f=150 mm **830** (Oriel), onto a 400 m p inhole **840** (Melles Griot Inc.), A second lens, f =150mm **850** (Melles Griot), creates a collimated light beam **875**, which is filtered by a filter wheel **860** consisting of three interference filters of center wavelength 634, 692 and 751 nm, respectively. All filters have a bandwidth of 10 nm. Said collimated beam is plane polarized by a dichroic sheet polarizer **870** (Melles Griot). The collimated light **875** impinges on an equilateral prism **880** made of BK7 glass (Melles Griot). Onto said prism is a glass substrate **883** attached by an index matching fluid (Cargille Inc.). The glass substrate contains the metal film supporting the surface plasmon resonance. The reflected light **877** from said prism **880** is projected on a CCD camera **920** (Orbis 2, Spectra Source Inc.) The camera is tilted to restitute the image.

All the references cited in this specification are included herein by reference.

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CLAIMS

1. A two-dimensional imaging surface plasmon resonance apparatus which comprises a sensor surface layer of a conductive material that can support a surface plasmon, a source of electromagnetic beams of two or more wavelengths that illuminate a two-dimensional surface area from either the front or the backside of the sensor surface layer, and a detector for simultaneous, or pseudo simultaneous, detection of two or more wavelengths of reflected intensities from the two-dimensional surface area, providing two or more two-dimensional images of the surface area, the two-dimensional images being a function of the effective refractive index at each point on the surface area.

2. The apparatus according to claim 1, wherein the conductive material is a free electron metal.

3. The apparatus according to claim 2, wherein the free electron metal is selected from the group consisting of gold, silver and aluminum.

4. The apparatus according to any one of claims 1 – 3, wherein the sensor surface layer is a grating.

5. The apparatus according to any one of claims 1 – 4, wherein a prism is provided as a support for the sensor surface layer.

6. The apparatus according to claim 5, wherein the sensor surface layer is supported on a planar transparent substrate plate, optically attached to the prism.

7. The apparatus according to claim 6, the planar transparent substrate plate is selected from glass and plastics, and the optical attachment is by an index matching fluid, gel or glue.

8. The apparatus according to any one of claims 1 – 7, wherein the light source is selected from the group consisting of a) one or more monochromatic light sources, b) a glowing filament lamp, and c) a charge discharge lamp.

9. The apparatus according to claim 8, wherein the light source a) is selected from the group consisting of light emitting diodes and lasers, the light source b) is a Tungsten lamp, and the light source c) is a Xenon or Mercury lamp.

10. The apparatus according to any one of claims 1 – 9, wherein the light from the light source is coupled into the sensor surface layer by a lens, a fiber optics, or a mirror.

11. The apparatus according to any one of claims 1 – 10, wherein the light source provides a variable incident angle.

12. The apparatus according to any one of claims 1 – 11, wherein the light from the light source is collimated.

13. The apparatus according to any one of claims 1 – 12, wherein the light of different wavelengths from the light source are pseudo-simultaneous impinging on the sensor layer by a rotating filter and are synchronized to the detector.

14. The apparatus according to any one of claims 1 – 13, wherein the detector is selected from the group consisting of a two dimensional array camera, charge coupled device (CCD), charge injection device (CID), photo diode array detector (PDA), photomultiplier and a CMOS sensor.

15. The apparatus according to any one of claims 1 – 14, wherein the detector has a mosaic filter.

16. The apparatus according to any one of claims 1 – 15, wherein two or more detectors are provided, and these are fitted with beam splitters and filters, such as interference filters, to enable measurement of different spectral properties.

17. The apparatus according to claim 15 or 16, wherein the filter(s) is(are) adjustable.

18. The apparatus according to any one of claims 1 – 17, wherein the detector(s) is(are) connected via an optical fiber bundle.

19. The apparatus according to any one of claims 1 – 18, wherein the detector is a photographic film.

20. The apparatus according to any one of claims 1 – 19, wherein a lens system, such as fixed focal length or a zoom, is provided to magnify or reduce the image.

21. The apparatus according to any one of claims 1 – 20, wherein the apparatus operates with wavelengths at or close to the highest slope of the dip, either reflectance versus wavelength or reflectance versus the effective refractive index seen by the surface plasmon.

22. The apparatus according to any one of claims 1 – 21, wherein the light that hits the detector is p-polarized by a polarizer.

23. The apparatus according to any one of claims 1 – 22, wherein the two-dimensional images put together result in a color image.

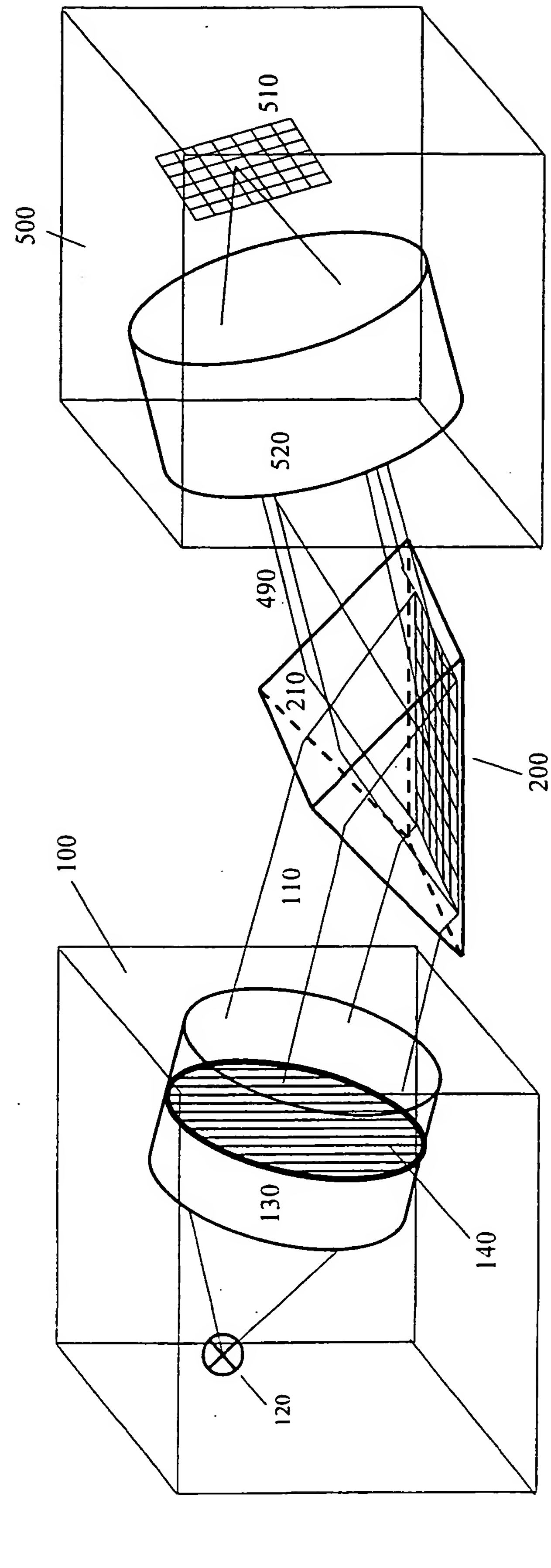
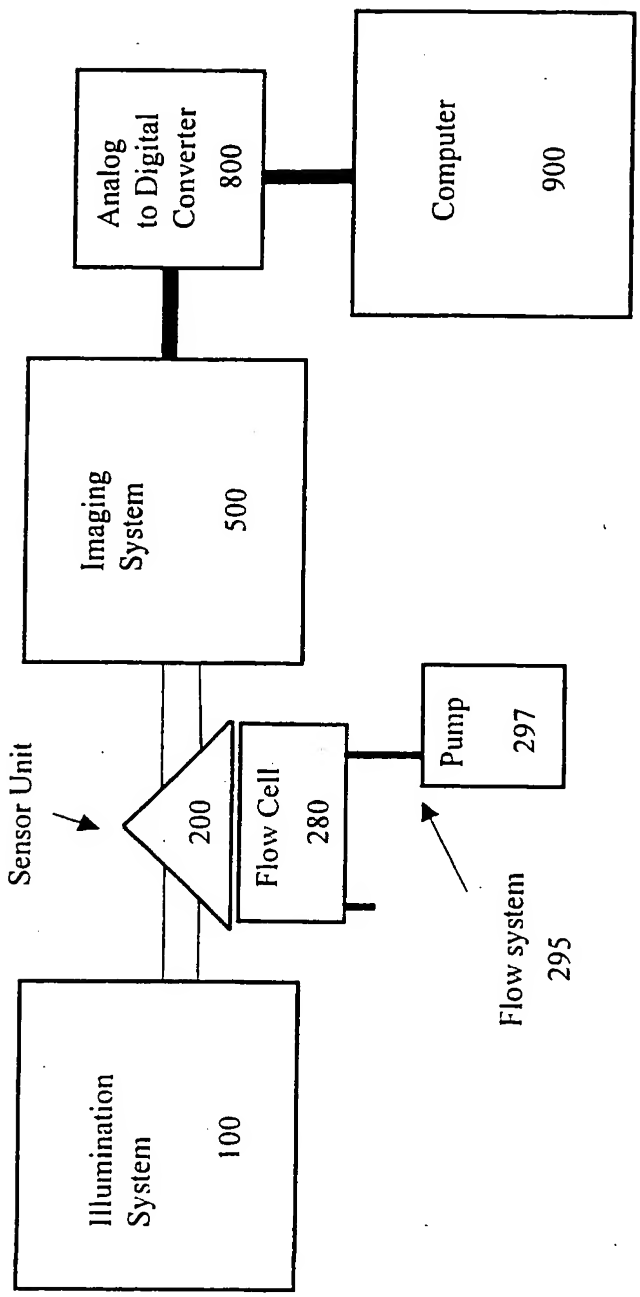


Fig. 1a


Analog
to Digital
Converter
800
Computer
900
Imaging
System
500
Sensor Unit
200
Flow Cell
280
Pump
297
Flow system
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Illumination
System
100

Fig. 1b

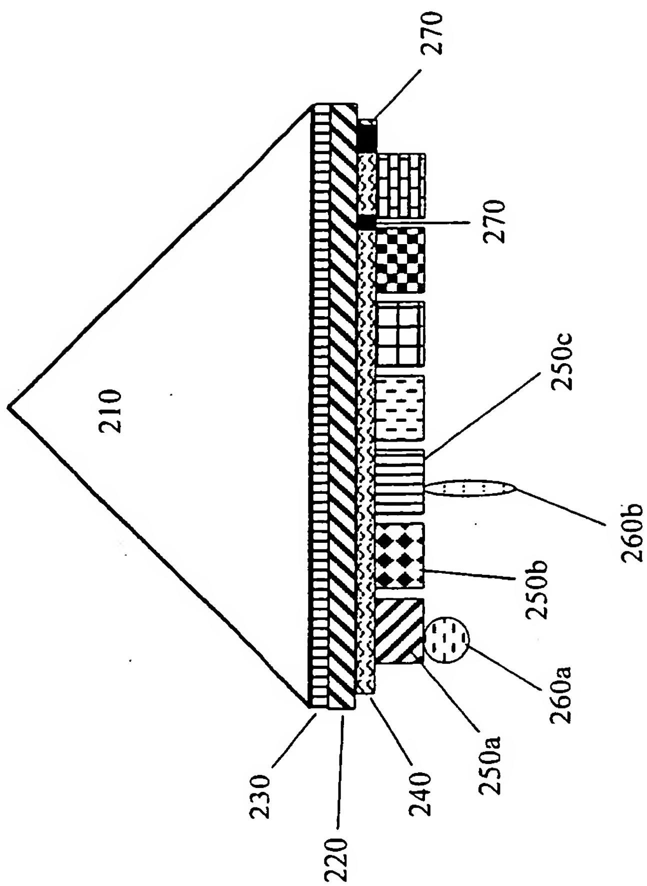


Fig. 2a

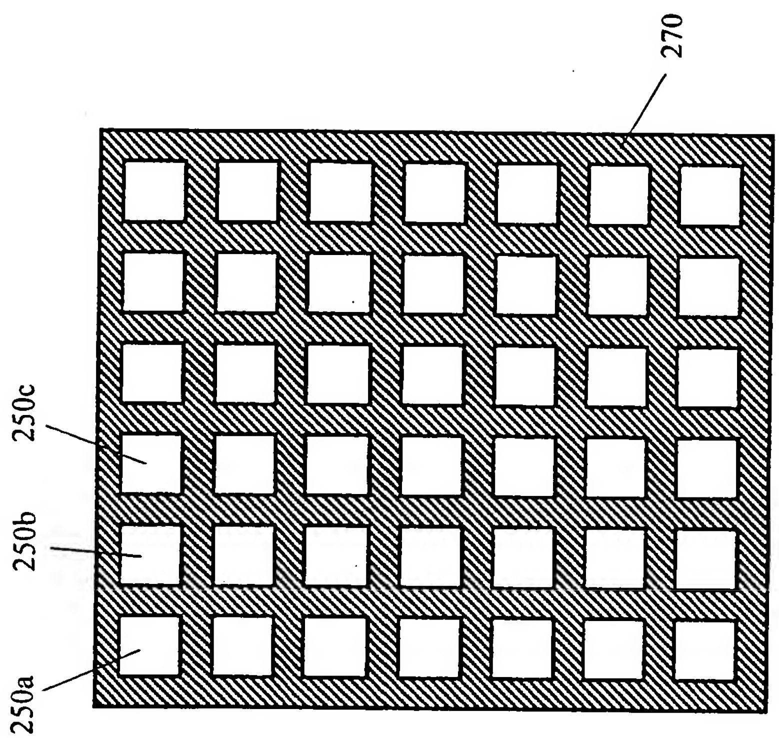


Fig. 2b

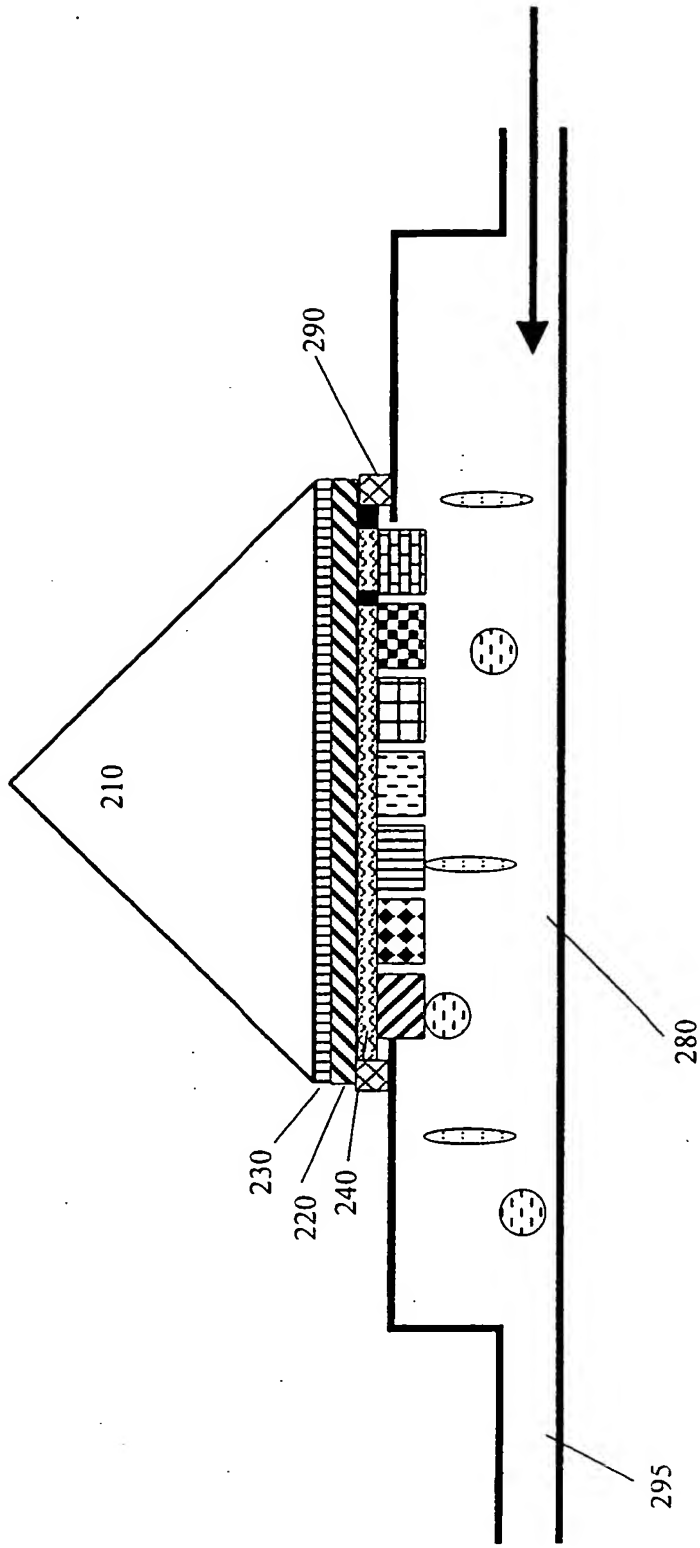


Fig. 2c

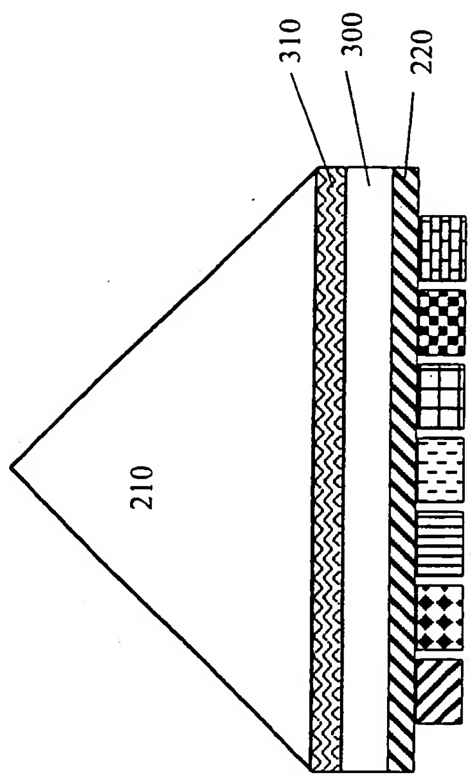


Fig. 2d

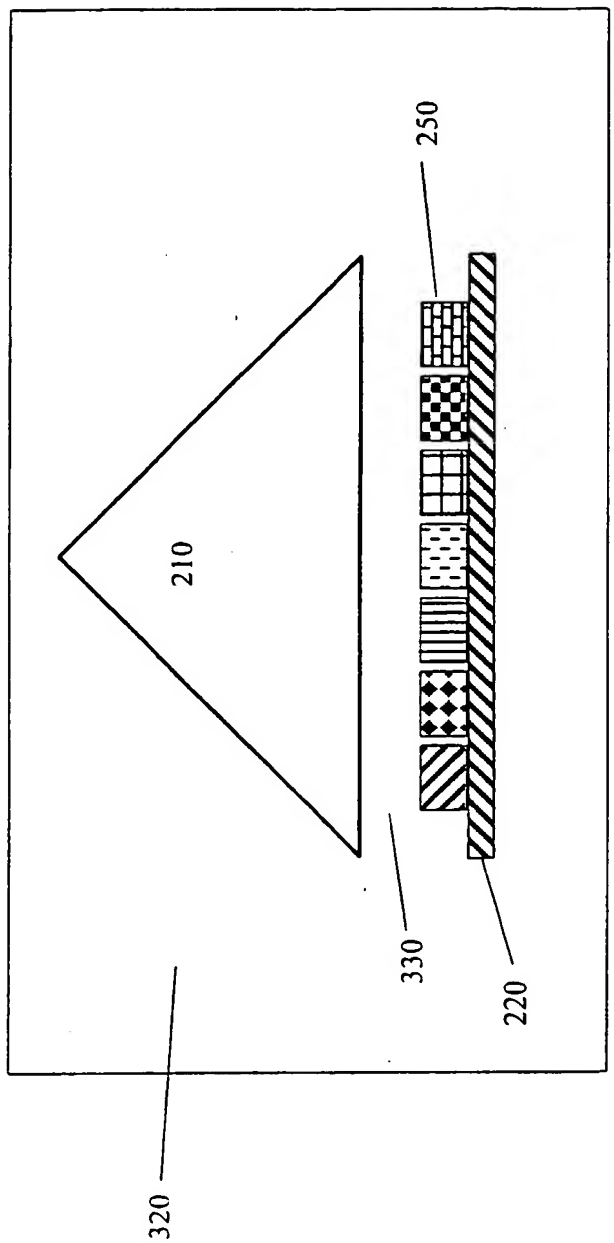


Fig. 3

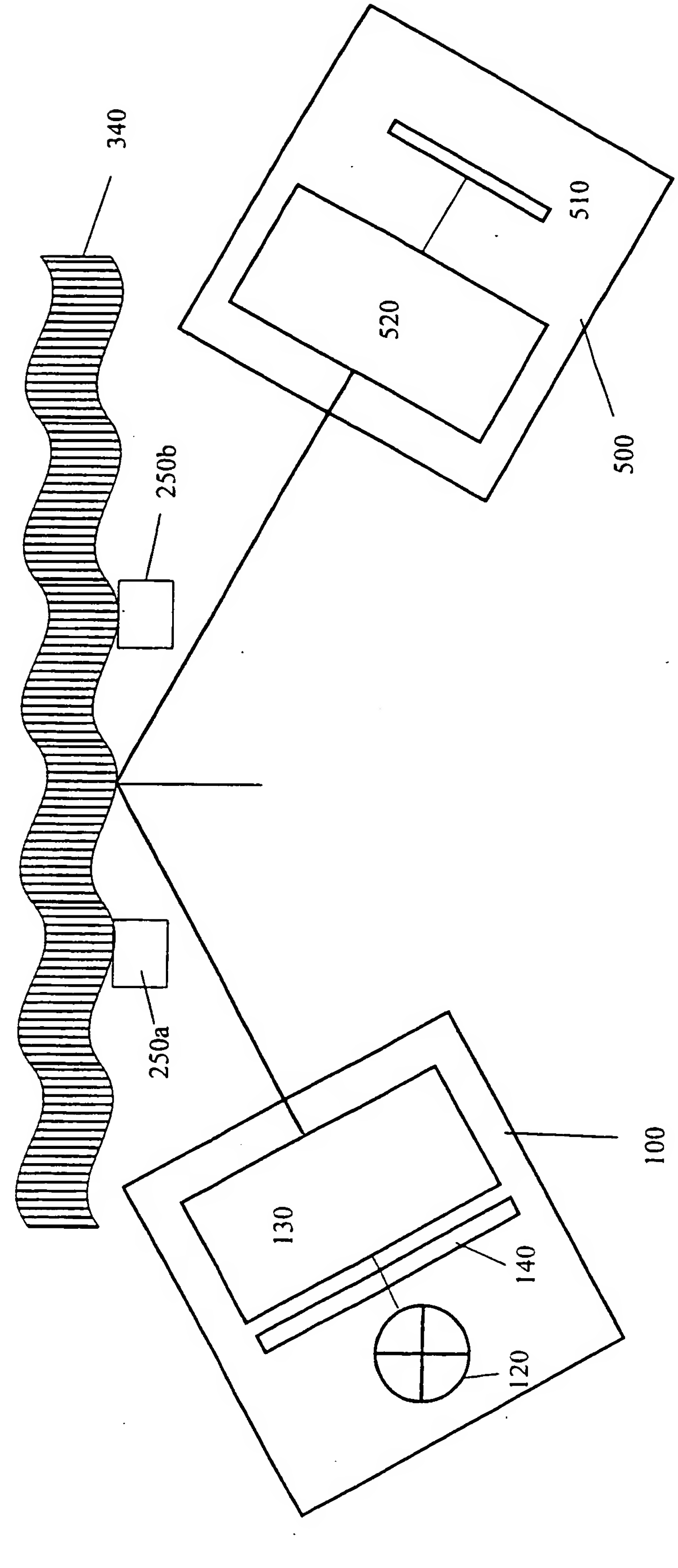


Fig. 4

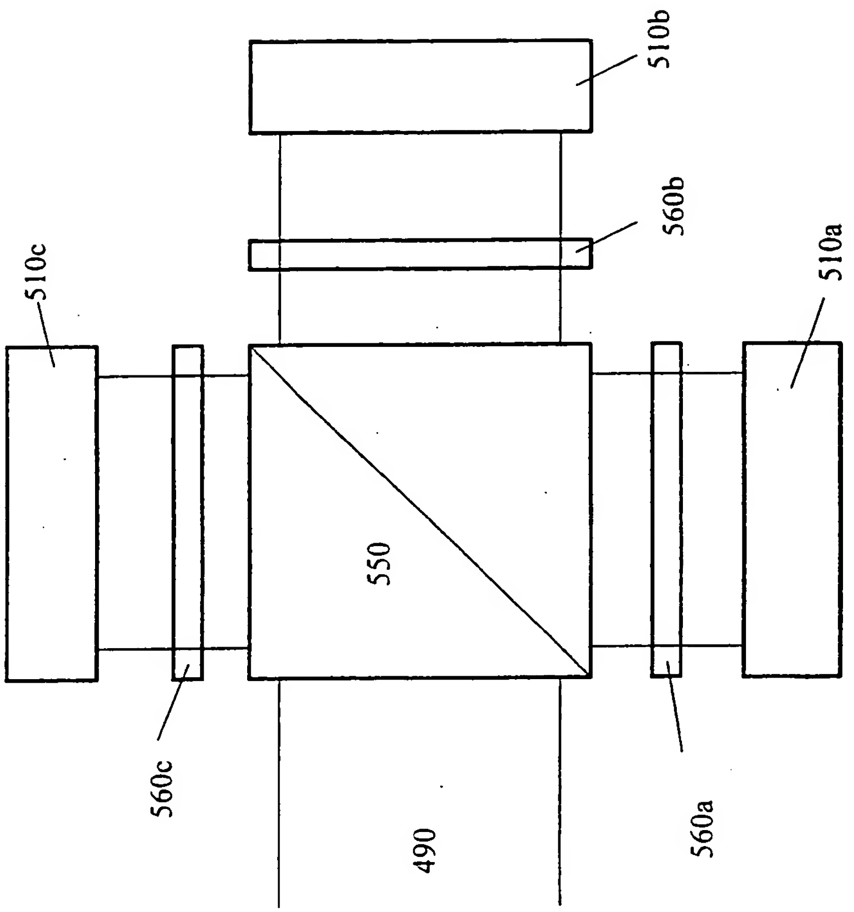


Fig. 5

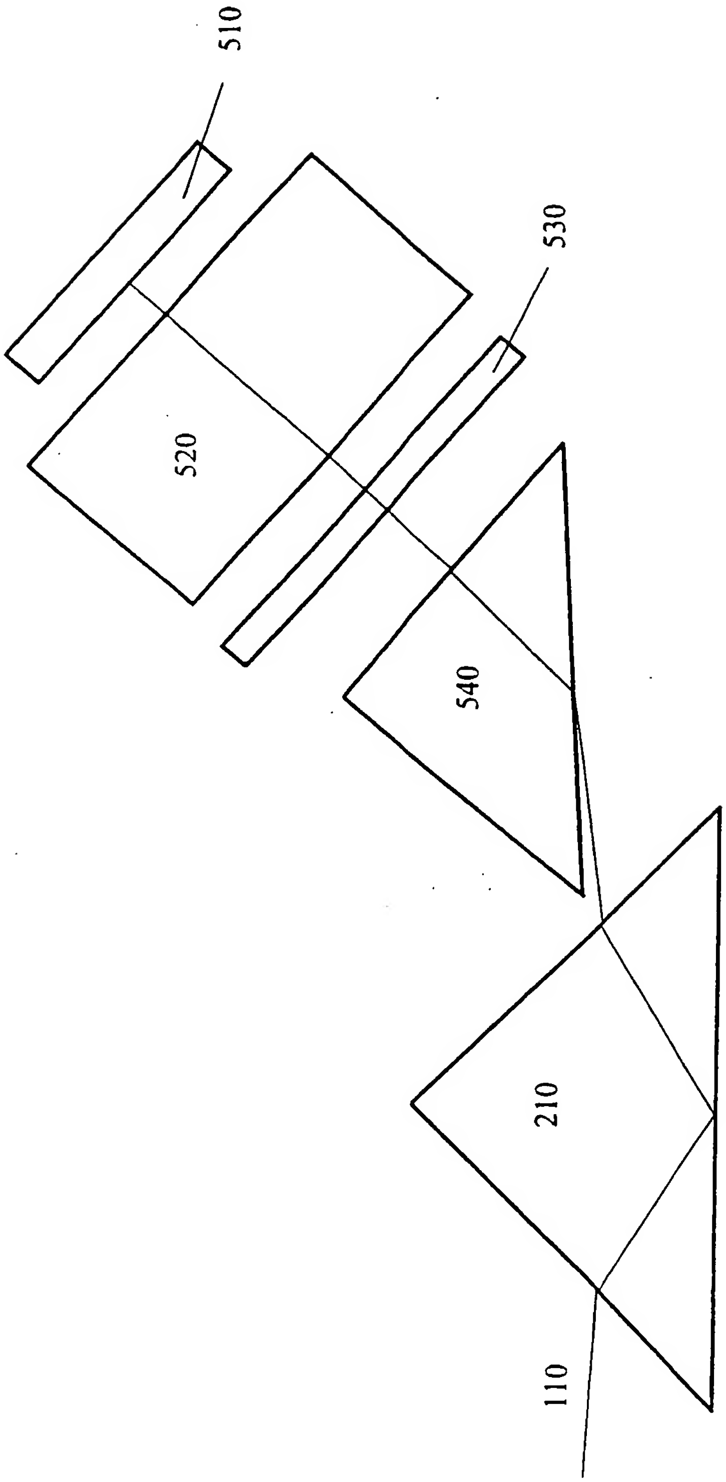


Fig. 6

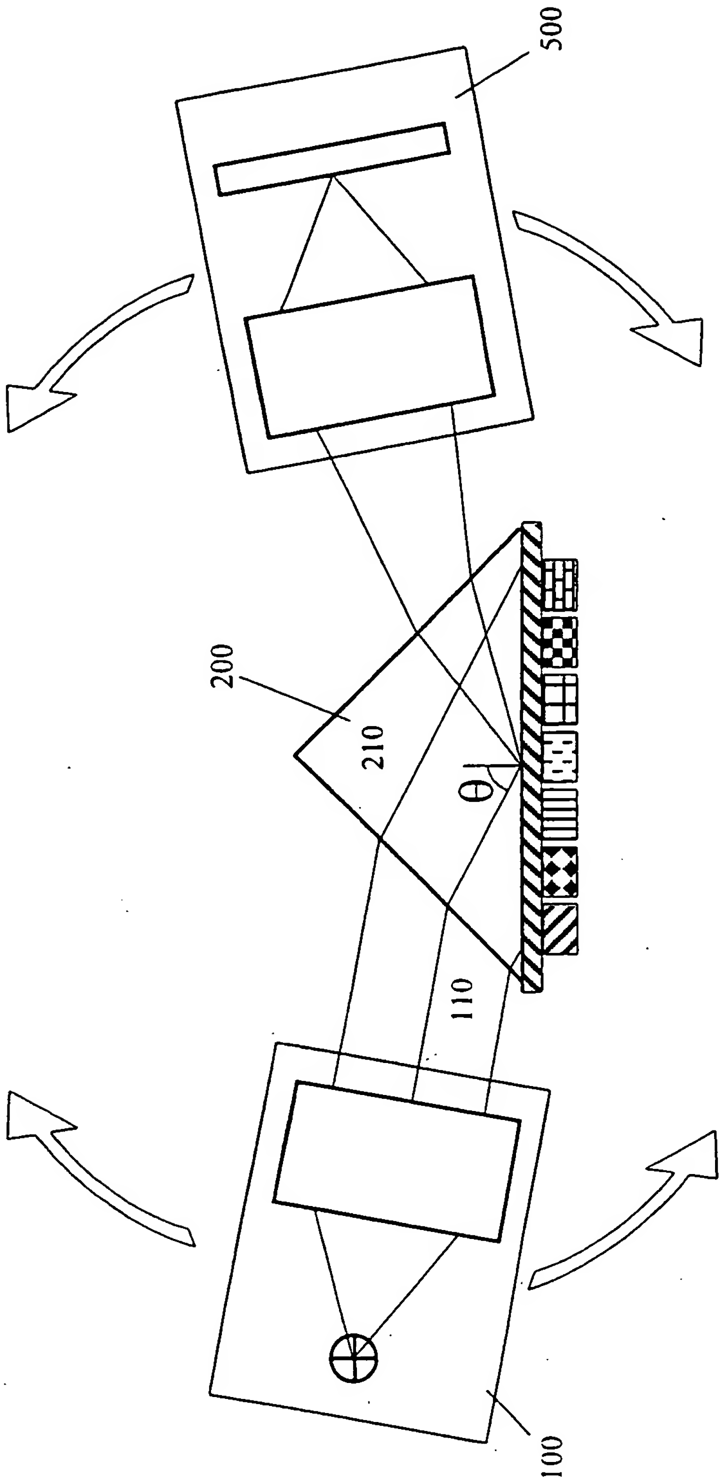


Fig. 7

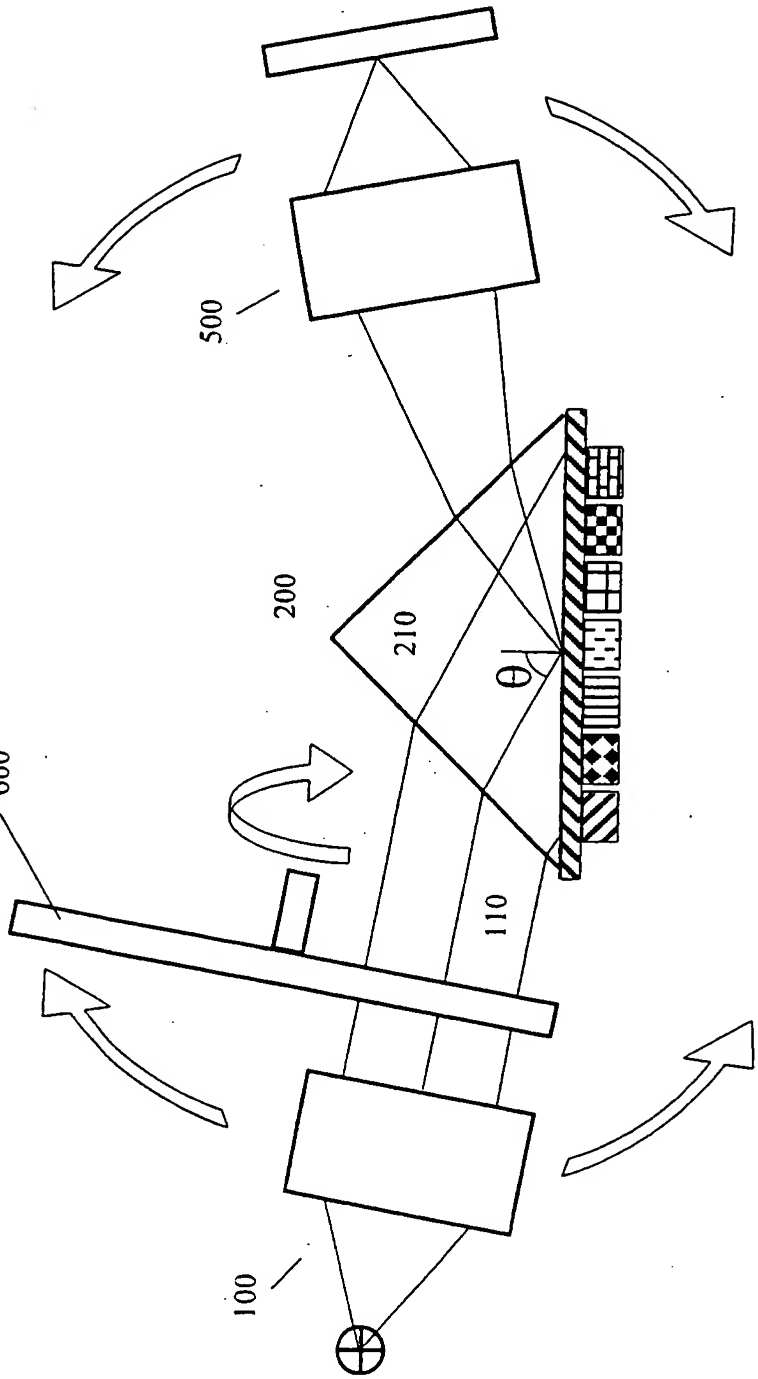


Fig. 8a

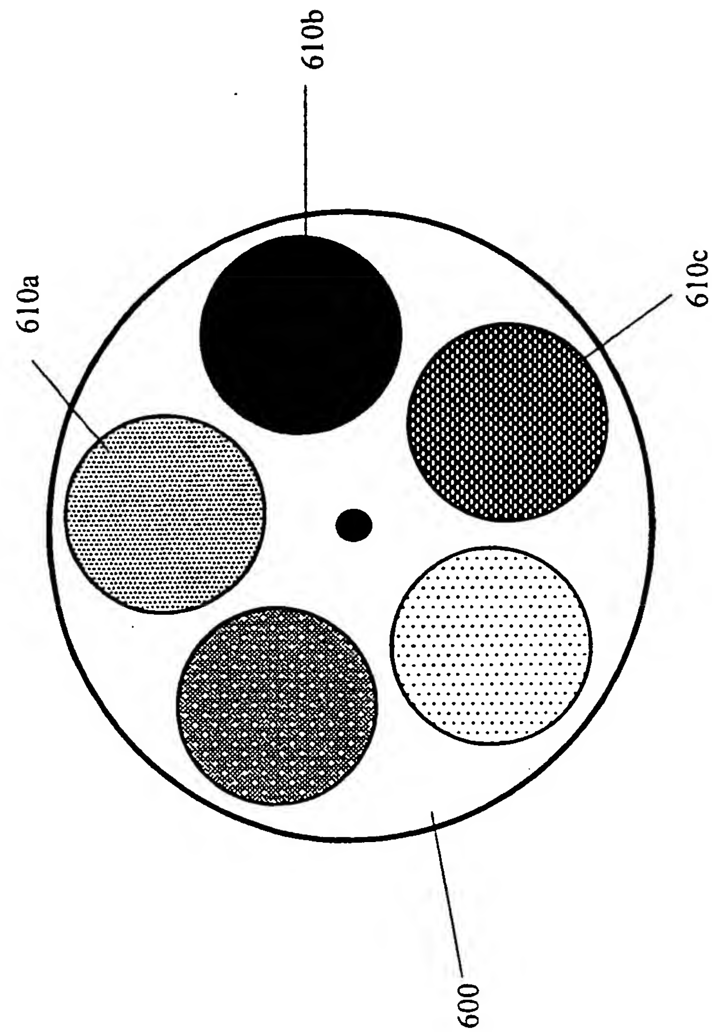


Fig. 8b

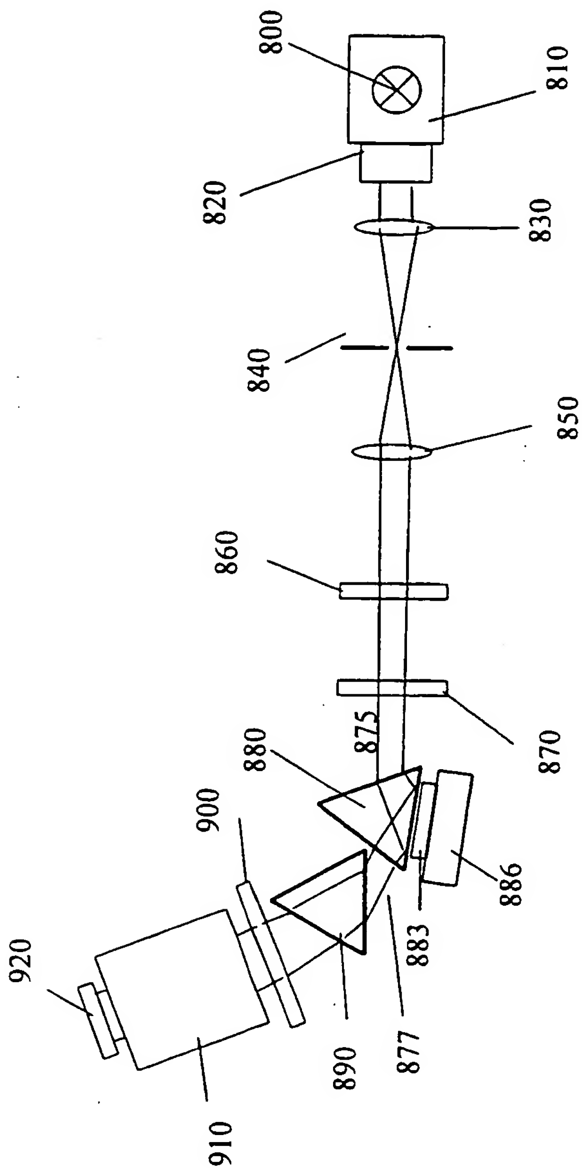

800
810
820
830
840
850
860
870
875
880
886
883
877
890
900
910
920

Fig. 9

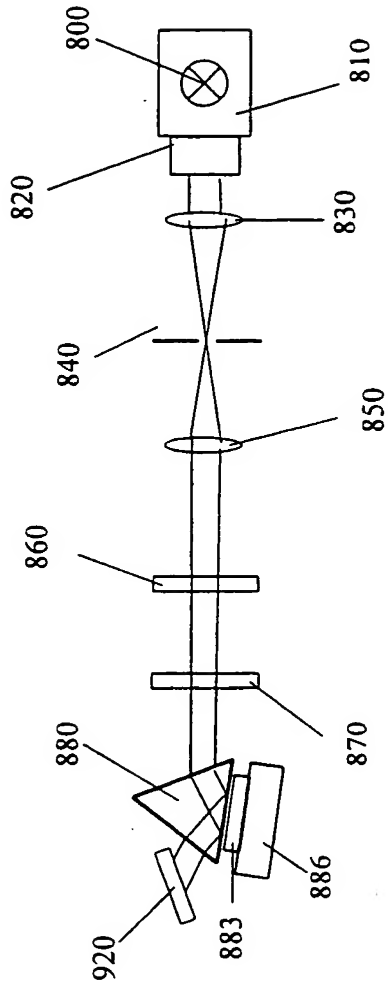


Fig. 10

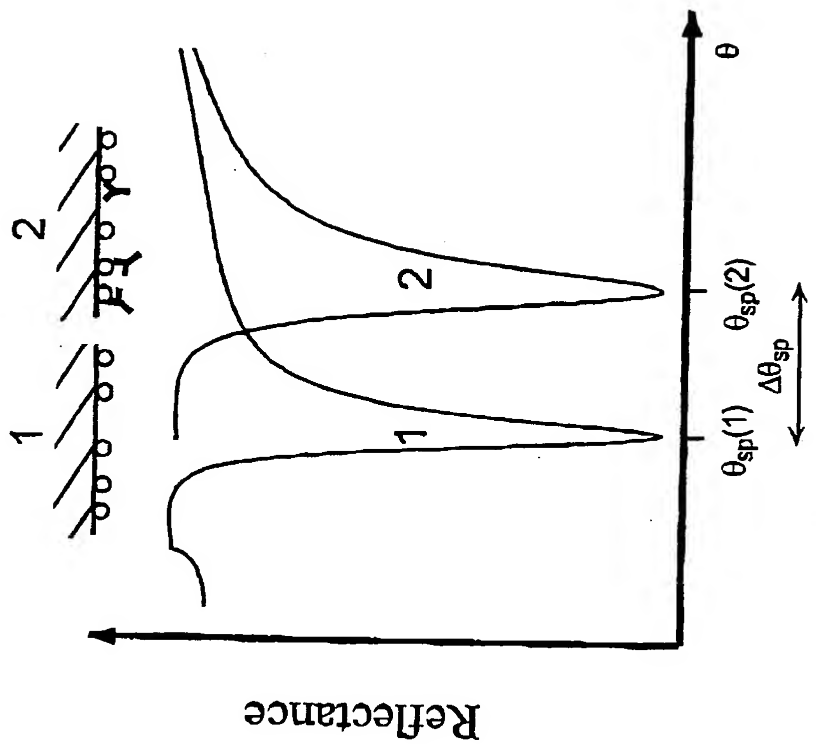
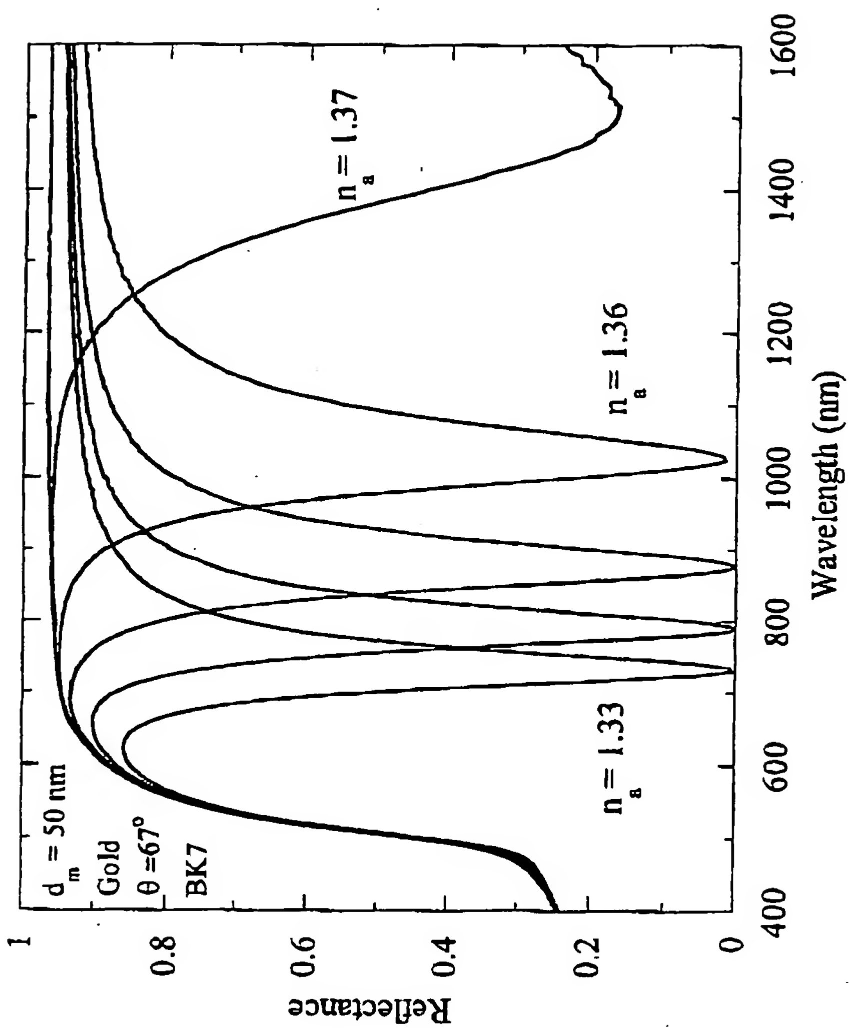


Fig. 11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Gold
θ =67°
BK7
n_a = 1.33
n_a = 1.36
n_a = 1.37
Reflectance
Wavelength (nm)
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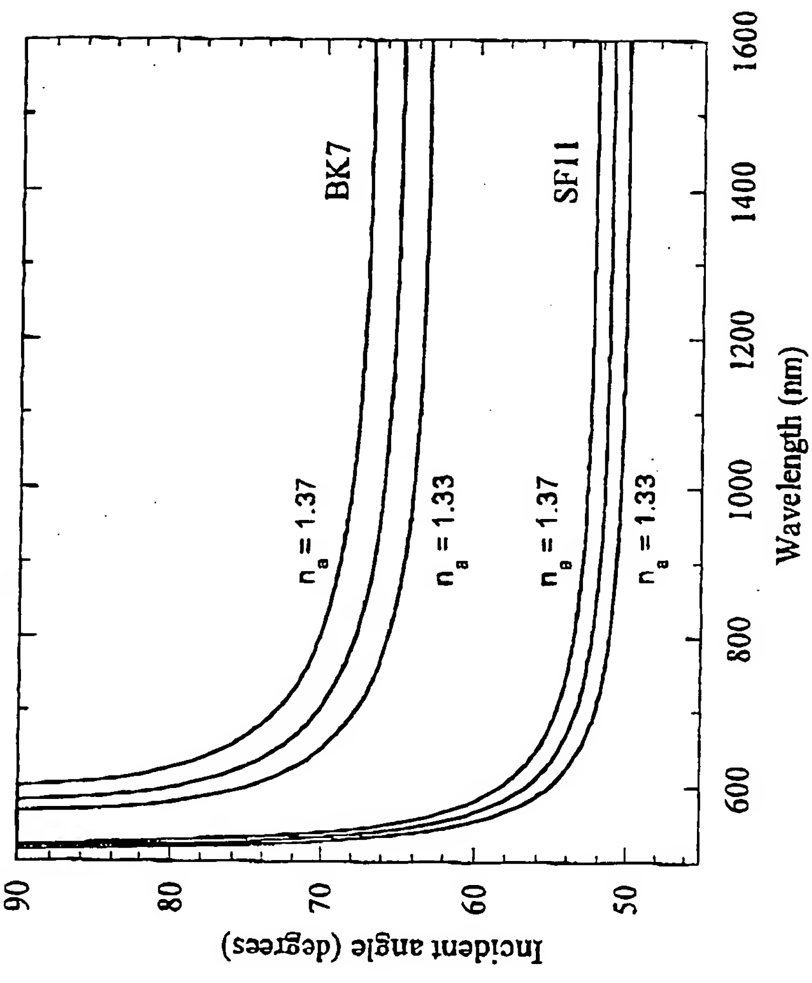
0.2
0.4
0.6
0.8
1
400
600
800
1000
1200
1400
1600

Fig. 12



BK7
SF11
n_a = 1.37
n_a = 1.33
n_a = 1.37
n_a = 1.33
Incident angle (degrees)
90
80
70
60
50
Wavelength (nm)
600
800
1000
1200
1400
1600

Fig. 13

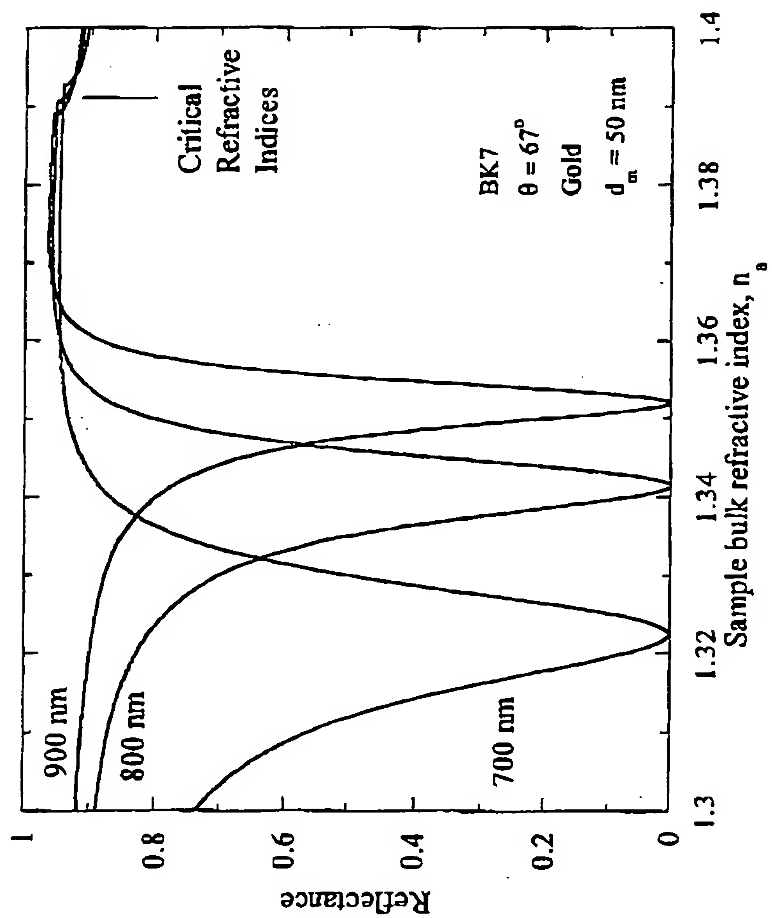

Reflectance
0
0.2
0.4
0.6
0.8
1
1.3
1.32
1.34
1.36
1.38
1.4
Sample bulk refractive index, n_a
900 nm
800 nm
700 nm
Critical Refractive Indices
BK7
θ = 67°
Gold
d_m = 50 nm

Fig. 14

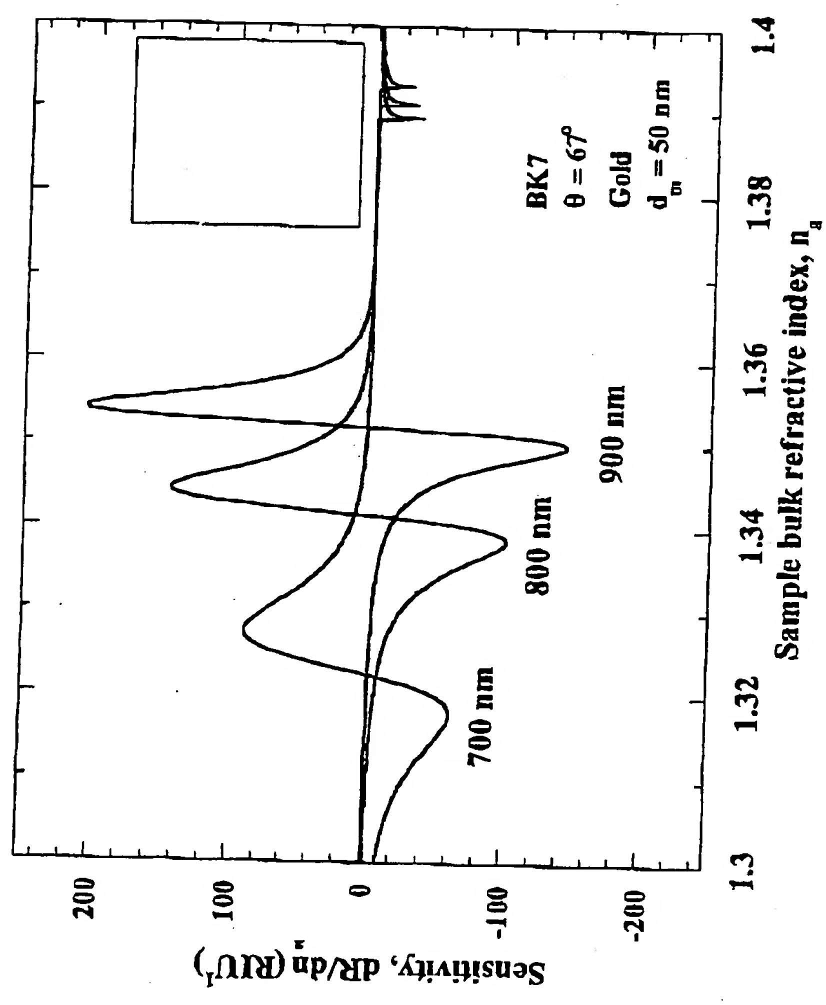
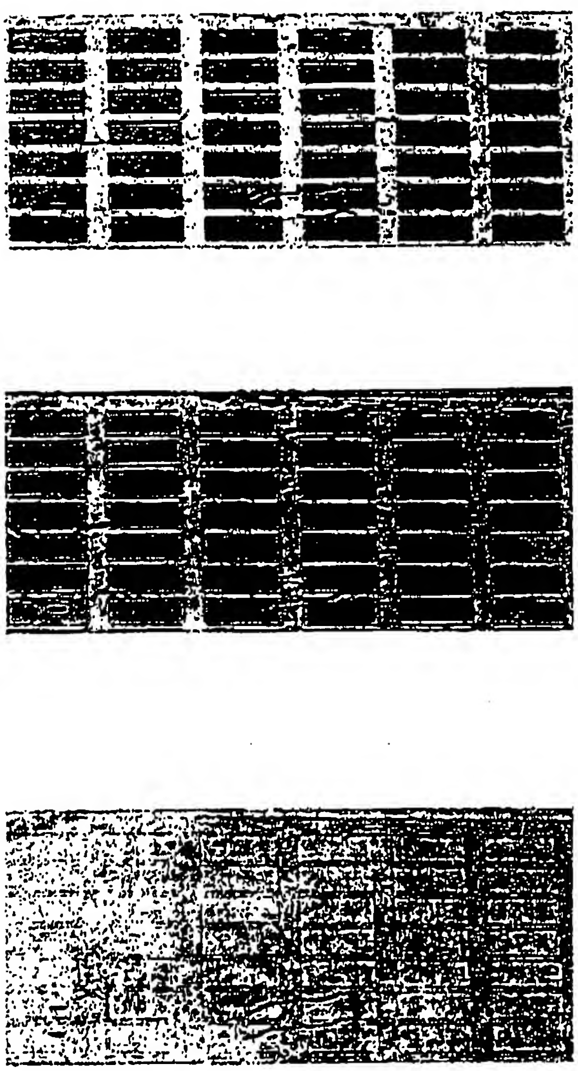

Sensitivity, dR/dn (RIU-1)
200
100
0
-100
-200
1.3
1.32
1.34
1.36
1.38
1.4
Sample bulk refractive index, n
700 nm
800 nm
900 nm
BK7
θ = 67°
Gold
d = 50 nm

Fig. 15



751 nm

692 nm

634 nm

Fig. 16

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/00530

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01N 21/55

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 9930135 A1 (THE PERKIN-ELMER CORPORATION), 17 June 1999 (17.06.99), page 13, line 11 - line 23; page 39, line 11 - line 15, abstract --	1-23
A	WO 9834098 A1 (BIACORE AB), 6 August 1998 (06.08.98), abstract -- --------	1-23

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 July 2001	13 -07- 2001
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Authorized officer Erik Westin/mj Telephone No. + 46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

02/07/01

International application No.
PCT/SE 01/00530

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9930135 A1	17/06/99	AU 1725999 A	28/06/99
		EP 1038167 A	27/09/00
WO 9834098 A1	06/08/98	AU 719654 B	11/05/00
		AU 1950497 A	22/09/97
		AU 5893198 A	25/08/98
		EP 0958494 A	24/11/99
		SE 9700384 D	00/00/00